

REHABILITATION OF THE OLD BEVIER PASSIVE TREATMENT WETLAND, MACON COUNTY, MISSOURI¹

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ABSTRACT

The Old Bevier Aerobic Wetland in Macon County, Missouri, was constructed between 1990 and 1991 by the Missouri Department of Natural Resources, Land Reclamation Program (LRP) for the purpose of treating Acid Mine Drainage (AMD). The principle source of the AMD is from an underground mine that operated during the 1920's through 1950's, which was partially exposed during surface mining in the 1950's. Limestone bedding of an AMD collection system provided alkalinity similar to an Anoxic Limestone Drain (ALD). Because the original aerobic wetland failed when a critical dilution water supply became unavailable, the total acidity of the AMD overwhelmed the limited neutralization ability of the aerobic wetland. The aquatic vegetation deteriorated and treatment became ineffective. The Missouri Land Reclamation Program with the assistance of the Office of Surface Mining, Mid-Continent Regional Coordinating Center rehabilitated the Old Bevier Aerobic Wetland in 2001, incorporating newer technologies to improve the performance. This paper describes the construction of an extended AMD collection pipeline, a 2-stage Vertical Flow Wetland System (VFWS) and associated oxidation cells and aerobic wetlands. The improved system is designed to treat 2.84 liters per second (45 GPM) AMD discharge with high iron (450 mg/L) and total acidity (760 mg/L), but low aluminum content (<2 mg/L). Initial evaluations find that effluent dissolved iron is 4.5 to 56 mg/L, net alkalinity (11 mg/L), and near neutral pH (5.3 to 6.95). Although no specific structures were incorporated in the design for manganese removal, manganese level in the discharge (7.9 mg/L) is significantly lower than the inlet level (10 mg/L). This initial evaluation was conducted during winter months and prior to the establishment of emergent vegetation. Improvements in metal removal are anticipated in the spring of 2002 upon establishment of aquatic vegetation and increased biologic activity.

INTRODUCTION

The Old Bevier II Reclamation Project in Macon County, Missouri, is located 11.2 kilometers southwest of the city of Macon in the watershed of the East Fork of the Little Chariton River (Figure 1). The project area is within the extensively mined Bevier-Ardmore Mining District, historically the most important coal-producing field in Missouri (Hinds, 1912). The extraction of coal began around 1859 in the field with Macon County coal production totaling 39 metric tons (43 million short tons) between 1889 and 1964 (Gentile, 1967). Room-and-pillar mining was extensive in the 1920's through the early 1950's, followed by area-type surface mining. The Bevier-Wheeler coal bed, composed of the upper, thicker Bevier and a lower, thinner Wheeler

coal bed, was the principle target of the mining. At the project site, the overlying 45.7-cm (18-inch) thick Mulky coal was also removed from surface mines (Gentile, 1967). The abandoned underground workings in the Bevier area generate, store, and transmit Acid Mine Drainage (AMD). The surface mining operations often intercepted this AMD and now convey the acid water to a series of seeps along the drainage channels. A number of small coal waste piles (gob) and acid-forming materials exposed by the surface mining generate additional AMD at the Old Bevier site. Several unnamed tributaries of the East Fork of the Little Chariton River are devoid of aquatic life and the river water is degraded by iron, manganese and sulfate from the mine area. Ground water level fluctuations and flushing of AMD from the underground workings during seasonal rainfall events lead to variations in the quality and quantity of water in these streams.

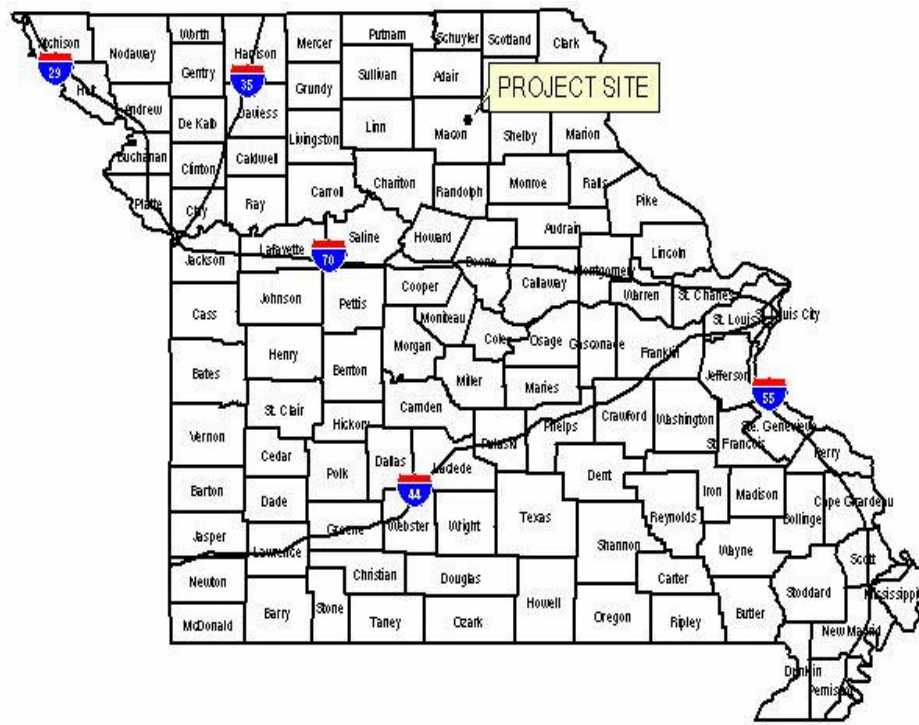


Figure 1. Location Map of the Old Bevier II Project Site.

The original Old Bevier Reclamation Project, designed by Metropolitan Engineering Co. (MECO) of Hannibal, Missouri, was subdivided into three project areas known as the North, South, and East Sites (Hare, 1992; Figure 2). Construction activity began on March 12, 1990, and was completed on April 30, 1991, at a total cost of \$932,089 U.S. The project reclaimed 18.6 hectares (46 acres) of abandoned mine lands, including three acres of gob, 121.9 meters (400 feet) of dangerous highwalls, and one vertical opening. An aerobic wetland, with its associated collection and dilution pipelines, was constructed at the South Site to treat AMD.

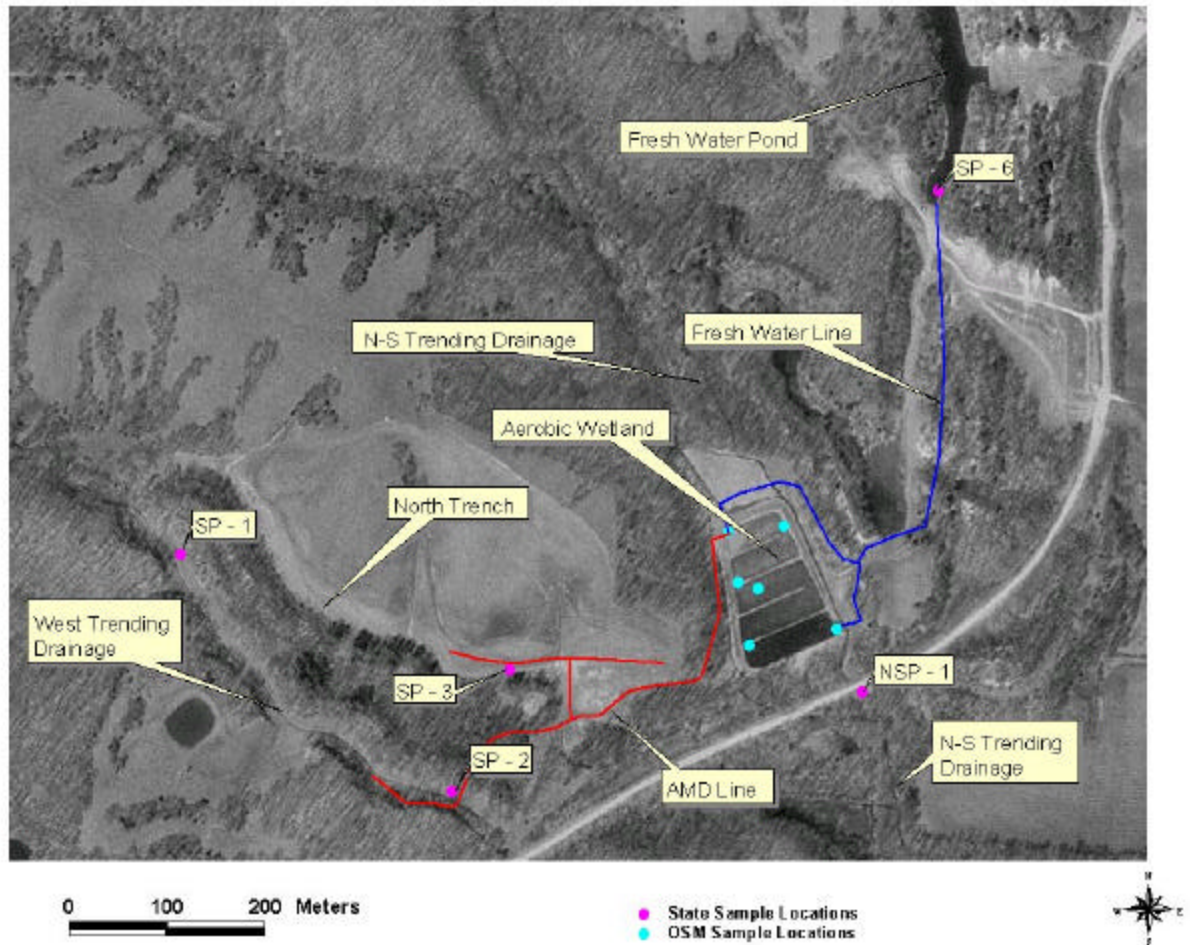


Figure 2. Water Sample Locations.

The South Site AML area is bound by two waterways. The main watercourse (its lower reach is just east of the aerobic wetland) loops around the site to the east and north. A second watercourse (the west trending drainage) flows out of the northwest and drains about 104 hectares (Figure 2). Multiple intermittent seeps, in part fed by underground mine workings, occur along these drainage channels at the base of exposed highwalls, coal outcrops, and spoil ridges. Spoil may be calcareous or acidic. The spoil ridges are often capped by acidic, black carbonaceous shale. Years of erosion deposited a 0.9 to 1.5 meter (3- to 5- foot) thick layer of acid-forming sediment in the watercourses.

The west-trending drainage was mined by contour-type surface methods (Figure 2). Contour mining there progressed along the west-trending drainage until the overburden reached a thickness of 9.1 to 12.1 meters (30 to 40 feet). A series of spoil ridges rose 7.6 to 15.2 meters (25 to 50 feet) above the surface of the watercourses in the former valley. A final cut was at the northern edge of this disturbance. This pit, known as the North Trench in the 1991 project, (Figure 2) was reclaimed to create a swale that parallels the original valley. Reclamation of the valley area consisted of covering the contaminated sediment with a 1.5 to 1.8 meter thick layer of clayey soil and reconstructing a new, elevated stream channel. The raised stream channel was designed to isolate surface drainage from an AMD-impacted zone in the old streambed. The final pit (North Trench in Figure 2) apparently intercepted underground workings and is the

principle source of AMD. Flow from this area was sampled at SP-3 (Figure 2 and Table 1). To the south, AMD flows from an outcrop of the Bevier coal. A pre-reclamation water sample of this AMD (Site SP-2) revealed elevated concentration of iron, manganese, and sulfate (Table 1, Figure 2). A French drain in the North Trench collects seepage and directs the AMD, along with water from a French drain in the west-trending drainage, into the original Old Bevier wetland.

Original Aerobic Wetland

Built as one of the earliest passive AMD treatment systems in the U. S., the Old Bevier Passive Treatment Wetland was initially effective in reducing iron loading, but less effective in reducing discharge acidity (Table 1 and 2; Hare, 1992). The key part of the original design for passive treatment included intake of alkaline fresh water from a nearby lake to increase pH and boost alkalinity. Although the wetland was designed to function as an anaerobic wetland it operated primarily as an aerobic wetland. Designed for a 3.78-liters-per-second [60 gallons-per-minute (GPM)] flow, the wetland was supplied by about 1.89 liters-per-second (30 GPM) of AMD from the two AMD-collection pipelines with the remainder from the fresh water source. A small, limestone-lined chamber at the entrance to the first wetland cell was designed to mix the two water sources (Figure 3).



Figure 3. 1998 Sampling of AMD at the Submerged Outlet of the Collection System (Wetland Inlet).

The original project consultant reported an initial 95% removal of iron, but water samples taken by the LRP in 1991 show higher iron concentrations (Table 1). The reduction of sulfate depended on an adequate supply of dilution water. Due to problems with the dilution source, only a minor reduction in sulfate was recorded in 1991 (Table 1; Hare, 1992). MECO also observed that the wetland behaved aerobically, (dissolved oxygen in the 4 to 5 mg/L range), but anticipated a shift to anaerobic-dominated treatment.

Table 1. Water Quality at the Old Bevier South Site Associated with the 1991 Reclamation¹

Parameter ²	SP-2 AMD from Southern Seeps: 1988	SP-3 AMD from Northern Seeps: 1988	AMD at Wetland Inlet: July 1991	SP-6 Dilution Water: East Site Last Cut Pit Source: 1991	SP-1 West Drainage: 1988 Data (New Dilution Water Source Considered in 2000)	Treated AMD at the Wetland Outlet: July 1991
pH	3.20	2.60	3.20	8.1	7.7	3.3
Total Alkalinity	pH < 4.3	pH < 4.3	pH < 4.3	103	168	pH < 4.3
Total Acidity	1,200	769	625	-57	-96	180
Dissolved Oxygen (DO)	6.3	5.5	NT	8.7	9.2	NT
Total Iron	502	90	299	0.36	1.18	18.10
Total Manganese	13.0	13.7	15.5	0.10	0.99	31.2
Total Aluminum	NT	NT	NT	NT	NT	NT
Sulfate	3,463	3,238	3,060	393	406	3,300
Total Dissolved Solids (TDS)	5,174	4,564	4,620	824	773	4,070

1. Samples collected by the Land Reclamation Program, 1988 through December 1991 and OSM-MCRCC in 1998 thru 2001.

2. All values are in mg/L except pH which is in Standard Units, NT = Not Tested.

Wetland Failure

The AMD treatment by the original aerobic wetland began on June 3, 1991. Emergent vegetation rapidly grew and covered most of the water surface during the first summer. Two consecutive years of drought dropped the pool level of the dilution lake limiting dilution water availability. Later, the fresh-water supply pipeline was damaged. By 1994, the pH in the third wetland cell dropped to about 2.9 because alkaline dilution water was not available to offset acidity released as oxidized dissolved metals (Figure 4). This low pH killed the aquatic vegetation and slowed metals removal. By 1996, the removal rate for iron remained about 92% due primarily to abiotic oxidation (Figure 4). Reductions in acidity, sulfate and manganese were not significant and iron removal deteriorated in latter years (Figure 5). The treatment facility required rehabilitation by 1998 due to failure of the dilution water source, and exhaustion of some of the carbon content of the compost, and accumulation of iron precipitate.

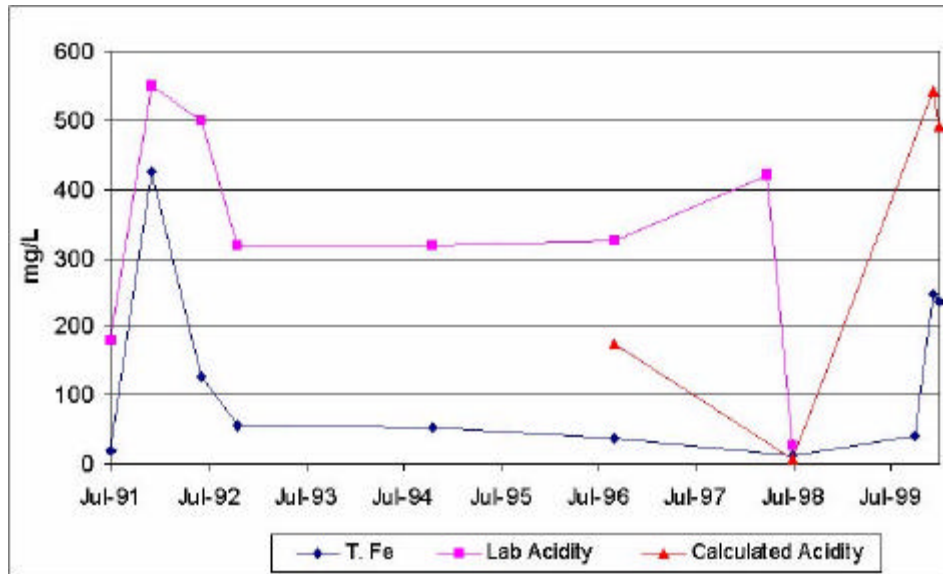


Figure 4. Total Iron and Acidity at the Outlet of the 1991 Old Bevier Wetland.

After completing a systematic hydrologic study in 1999, the LRP and Office of Surface Mining Mid-Continent Region Coordinating Center (OSM-MCRCC) found that the failure of the dilution water supply was the principle problem with the original system. Although the AMD coming into the wetland contained high alkalinity derived from the limestone bedding of the collection pipeline (about 120 to 180 mg/L as equivalent CaCO_3 , Tables 1 and 2), additional alkalinity from the dilution water was needed to offset the acidity (about 620 to 760 mg/L) of the AMD.

HYDROLOGIC INVESTIGATION AND INITIAL CONSTRUCTION ACTIVITY

By early 1998, the LRP/OSM-MCRCC project team decided to conduct a comprehensive hydrologic study at the constructed wetland site to better understand the nature of the AMD. The goal of this study was to gather the scientific and engineering data necessary to transform the Old Bevier Passive Treatment Wetland into an improved passive treatment system. This project was also intended to give the team experience applying recent treatment innovations to the design and construction of AMD abatement facilities. Similar technology might then be employed at other AML sites in Missouri.

Passive treatment is often enhanced when AMD can be collected as anoxic (<1.0 mg/L dissolved oxygen) flow. To best characterize water quality, the AMD should be collected and analyzed in the same chemical state as found in the field. To accomplish this, anoxic water may be sampled from a well, a wet-type mine seal, or an existing AMD collection pipeline as at Old Bevier. The outlet of the drainage collection system at the center of the mixing chamber (Figure 3) was inaccessible because it was submerged and buried in iron floc. A valve-controlled tap in the collection pipe was installed during Phase I construction (Figure 6). From the tap, a 10.2 cm (4-inch) PVC pipe conveys flow for temporary bypass treatment. It provides a means to collect AMD, the characterization of which is critical to the redesign effort, and allows a standpipe connection for water head measurement. The Phase I activity also involved construction of an all-weather access road and facility area near the southwest corner of the original wetland.

Table 2. Pollutant Loading at the Old Bevier South Site applicable to 1991 Reclamation¹

<u>Location/ Constituent</u>	<u>Concentration¹ (mg/L)</u>	<u>x Flow Rate² L/sec (GPM)</u>	<u>x Conversion Factor (86.4)</u>	<u>= Loading (grams/day)</u>
<u>Inlet AMD</u>				
Total Iron	299	1.89 (30)		48,887
Manganese	15.5	1.89 (30)		2,534
Acidity	625	1.89 (30)		102,188
Alkalinity	0	1.89 (30)		0
Sulfate	3,060	1.89 (30)		542,820
<u>East Lake Dilution Source</u>				
Total Iron	0.36	1.89 (30)		59
Manganese	0.1	1.89 (30)		16
Acidity	-57	1.89 (30)		-9,320
Alkalinity	103	1.89 (30)		16,841
Sulfate	393	1.89 (30)		64,256
<u>Pre-Reconstruction Passive Treatment System Outlet</u>				
Total Iron	18.1	1.89 (30) ⁴		2,959
Manganese	31.2	1.89 (30) ⁴		5,101
Acidity	180	1.89 (30) ⁴		29,430
Alkalinity ³	0	1.89 (30) ⁴		0
Sulfate	3,300	1.89 (30) ⁴		539,550

1. The Land Reclamation Program collected samples in 1988 through 1991.
2. Flow values are estimates.
3. Estimated to approximate 0.00 when pH < 4.3.
4. Discharge was 37.9 L/ sec. (60 GPM), dilution source failed.

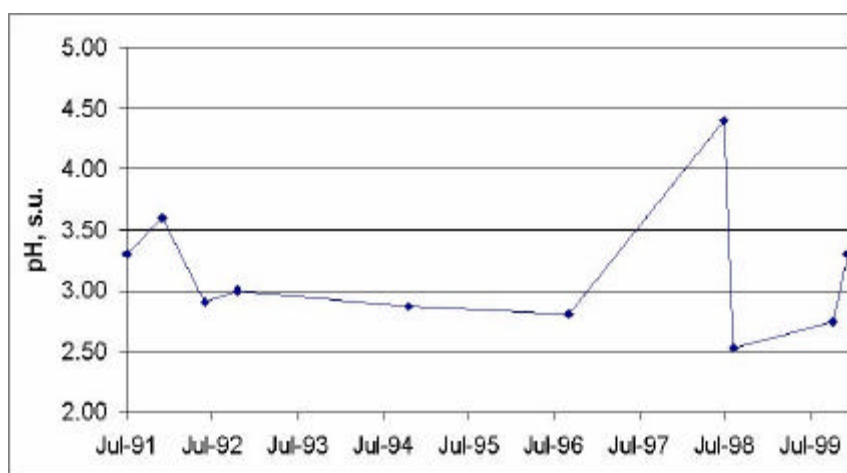


Figure 5. Change in the pH with Time: Outlet of the 1991 Old Bevier Wetland.

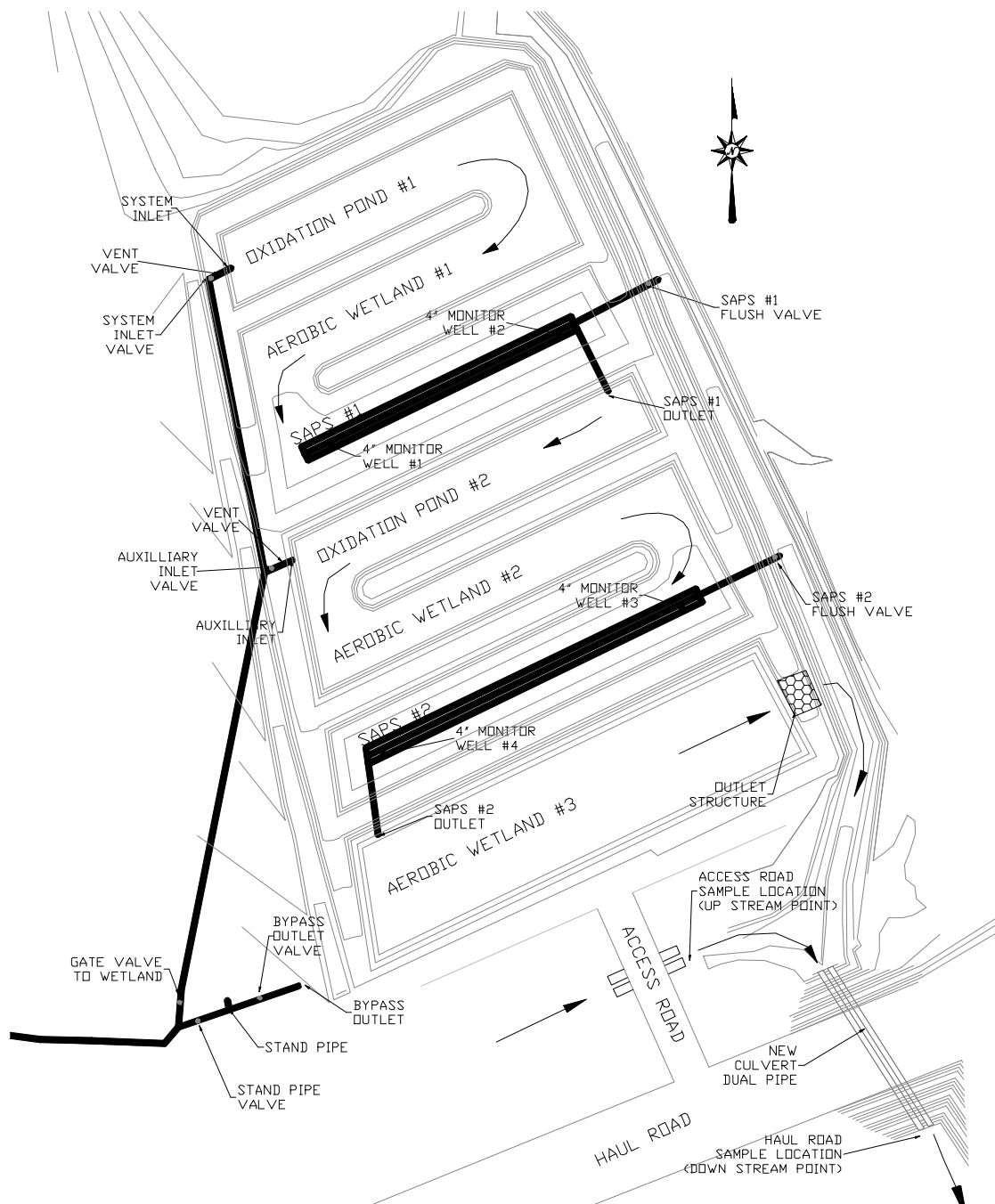


Figure 6. Passive Treatment System of the Old Bevier II Project.

Water Sampling and Analysis

Although some historical AMD water data were available, there was uncertainty about methods employed for field measurements and analyses. Also, there were little or no data on some critical parameters such as aluminum. Systematic water sampling was performed over a two-year period during 1998 and 1999 (Behum et. al., 2001). The parameters selected to characterize the AMD were those suggested by Hyman and Watzlaf (1995) and Wildeman and

others (1997) and include dissolved metals (iron, aluminum, and manganese) and sulfate. The important measurements of both ferric and ferrous iron were also taken during the late 1990s. Total and ferrous dissolved iron concentrations were determined in the field with a portable colorimeter. Dissolved ferric iron values were calculated by subtracting ferrous iron from the total dissolved iron. Similarly, this method was used to estimate total metal values using an unfiltered sample. No attempt was made to directly measure ferric iron in the field as suggested by Wildeman and others (1997). Additional field measurements included temperature, pH, redox potential (Eh), conductivity, salinity, dissolved oxygen (DO), and total alkalinity, using either electrochemical or titration methods. Total acidity was also determined in several rounds of lab tests and supported by calculation methods (Hyman and Watzlaf, 1995). Water samples were collected consistent with standard methods (Eaton and others, 1995).

Jar Test

A Vertical Flow Wetland System (VFWS) was being considered as a possible technology for use in remediation of the wetland. Before this design could be completed, locally derived limestone was evaluated for alkalinity production potential. This task used a modified version of the Jar Test method suggested by Watzlaf and Hedin (1993). A 18.9-liter (5-gallon) plastic carboy was filled with locally quarried limestone. This container was then filled with AMD from the sample site and placed in a cooler with some ice to maintain a temperature similar to the groundwater. Samples were then drawn over the next several days and the total alkalinity was measured (Hach digital titration method). Data were plotted on a chart to show the rate of alkalinity generation (Behum et. al., 2001). Two replicates of the test were run to ensure data consistency. The tests showed that the potential increase in alkalinity using this limestone and AMD combination was 160 to 190 mg/L.

Temporary Chemical Treatment

A popular device commercially known as an *Aquafix* system² (Aquafix Water Treatment Systems, Kingwood, WV) chemically treated diverted AMD while construction progressed on the wetland. The unit was connected to the sampling outlet constructed in Phase 1 and the flow to the wetland was turned off. *Aquafix* treatment of the AMD continued over the course of the construction activity.

PASSIVE TREATMENT

Following the hydrologic investigations, Missouri LRP and OSM-MCRCC developed design options for the improvement of passive treatment at the site.

Design Options

The data suggested consideration of three different design options to rehabilitate the wetland. These options included:

OPTION 1

Dilution Pond Construction and Aerobic Wetland Rehabilitation. An adequate amount of suitable alkaline dilution water could be obtained by constructing a new 7,402 cubic meter (6 acre-foot) impoundment. A rebuilt pipeline from the East Site freshwater impoundment (Figure 2) could deliver the dilution water. Table 3 provides the loading calculations used in this evaluation. As in the original design, this plan has dilution water alkalinity offsetting AMD acidity. An aerobic wetland would provide a favorable environment for the precipitation of metals contained in the AMD/alkaline water mixture. The new dilution water source would be located upstream from the surface mining area and was expected to have relatively high water quality (Tables 1 to 3). Note that both dilution sources have elevated sulfate (>300 mg/L), which would contribute to sulfate loading (Tables 2 and 3).

OPTION 2

Dilution Pond and VFWS Construction with Aerobic Wetland Rehabilitation. This option only uses dilution water from the new, 7,402 cubic meter (6 acre-foot) impoundment as an alkalinity source (Table 3, west dilution source) to partially offset the AMD acidity. However, additional alkalinity is required (compare acidity loading from the inlet to the AMD load of the outlet, Table 3). A Vertical Flow Wetland System (VFWS)-also known as a Vertical Flow Pond- provides the remaining alkalinity. The VFWS is a deepwater pond with piping that drains the AMD/dilution water mixture downward through a layer of compost, through an alkalinity source (a bed of limestone), and out through collection pipes and water level control structure. The critical step is the removal of dissolved oxygen by the deep water and compost. This shift in the redox potential prevents metal precipitation in the limestone bed, which would reduce the life of the system. A downstream aerobic wetland would then provide a favorable environment for precipitation of metals.

OPTION 3

Two-Stage VFWS / Anaerobic Wetland Treatment. Option 3 does not require the use of dilution water to partially offset the acidity. Instead, alkalinity is generated in a two-stage VFWS. Because of the high acidity of the untreated AMD (Tables 1 - 3), additional alkalinity may be required. An aerobic wetland, operating in series with the VFWS, produces this alkalinity from limestone and bacteria-mediated sulfate reduction reactions within its thick compost layer.

PHASE II DESIGN

In assessing design options, the LRP was concerned that, due to site topography, a dilution pond would have to be located remote from the treatment system in a heavily wooded area. This would require a pipeline, a feature that had been employed for the original treatment system, and proved to be troublesome. Also, project costs would have increased from clearing, grubbing, and earthwork associated with dam and impoundment construction in a wooded area.

Based on the above considerations and a review of data collected during the hydrologic evaluation (Tables 1-3), the LRP decided to implement option 3-a two-stage VFWS system with

associated wetlands and oxidation ponds. Design option 3 calls for the final treatment cell to be an anaerobic wetland. Instead, however, a hybrid aerobic/anaerobic cell was built with a thin (30 cm) layer of organic matter covering a 30-cm-thick limestone gravel bed. This cell is submerged under 15 cm of water. This paper generally refers to the final cell as an aerobic wetland.

- weather conditions;
- geologic setting;
- shape and configuration of the treatment cells;
- AMD chemistry;
- age of the system;
- nature and quality of compost and limestone;

The design criteria are:

2. *mass of limestone needed* = $M_1 + M_2$

$$M_l \text{ (mass of limestone gravel needed to achieve water retention time)} = Q * L_d * R_t / V_d$$

Q = flow rate

 R_t = water retention time
$$V_d = \text{limestone gravel porosity}$$

A_p = alkalinity productivity (fraction of limestone that is CaCO_3)

T_1 = effective life of system

A_g = expected alkalinity concentration to be generated (160 mg/l was used based on the Phase I study's modified Jar Tests).

Because the concentrations of aluminum and manganese are insignificant compared to the total iron concentration, iron is the limiting factor. Therefore, the iron removal rate was used to size the aerobic wetland cell. The oxidation ponds were sized to provide at least 24 hours of water retention time and to store iron floc for the project life. Manganese and sulfate levels were also relatively high. However, cost and space limitations of the project prevented inclusion of specific structures for manganese or sulfate removal. Such facilities could have included a large anaerobic wetland for sulfate reduction and/or a limestone bed inoculated with manganese-removing bacteria.

Constituent	Concentration¹ mg/l)	x Flow Rate L/sec(GPM)	x Conversion Factor 86.4	= Loading (g/day)
<u>Inlet AMD</u>				
Total iron	450	1.893 (30)		73599
Manganese	15	1.893 (30)		2453
Acidity	761.7	1.893 (30)		124580
Alkalinity	180	1.893 (30)		29393
Sulfate	3400	1.893 (30)		556088
<u>East Lake Dilution Source</u>				
Total iron	0.36	2.524 (40)		79
Manganese	0.1	2.524 (40)		22
Acidity	-57	2.524 (40)		-12430
Alkalinity	103	2.524 (40)		22462
Sulfate	393	2.524 (40)		85703
<u>West Lake Dilution Source (proposed)</u>				
Total iron1.	18	2.524 (40)		257
Manganese	0.99	2.524 (40)		216
Acidity	-96	2.524 (40)		-20935
Alkalinity	168	2.524 (40)		36636
Sulfate	406	2.524 (40)		88538
<u>Resultant : AMD + East Lake + Proposed West lake</u>				
Total iron	123.3	6.94 (110)		73935
Manganese	4.5	6.94 (110)		2691
Acidity	152.1	6.94 (110)		91184
Alkalinity	147.6	6.94 (110)		88508
Sulfate	1217.8	6.94 (110)		730082
<u>Resultant : AMD + East Lake only</u>				
Total iron	193.1	4.417 (70)		73678
Manganese	6.5	4.417 (70)		2475
Acidity	293.9	4.417 (70)		11211212
Alkalinity	136.0	4.417 (70)		51860
Sulfate	1681.7	4.417 (70)		641791

1. “Lake” Samples collected in 1988 by the Land Reclamation Program. “Inlet AMD” is an average of State and OSM values collected as of the 1999 dilution option studies and approximately represent the inlet quality at the time this paper was prepared.

The VFWS cells, designed for a 20-year effective life, contain a 1.3-meter (4-foot) thick layer of limestone in VFWS #1 and a 0.91-meter (3-foot) thick layer in VFWS #2. Overlying the limestone beds are a 0.46-meter (1.5-foot) thick layer of organic matter and then a 0.61-meter (2-foot) of water. Because of the limited amount of elevation head available at these sites the latter two layers are slightly thinner than the standard VFWS design. Most of the organic matter is mushroom compost shipped from the Miami, Oklahoma area. The VFWS units are constructed with 15.2 cm (6-inch) and 20.3 cm (8-inch) Schedule 80 PVC underdrain piping and Agri Drain Corporation’s (Adair, IA) *Inline Water Level Control Structures*³. 20.3 cm (eight-inch) Schedule

80 PVC piping and control valves provide a flushing capability to each VFWS unit (Figure 7) as suggested by Skovan and Clouser (1998) and Cavazza (1999). The retention time in VFWS #1 is 15 hours and VFWS #2 is designed for 12 hours. The aerobic wetlands are designed with 0.46 meter (1.5-foot) thick layer of compost, which is mostly composed of a manufactured product from Chamness Technologies (Eddyville, IA). The aerobic wetland cells are also designed for a 12-hour retention time. Water depth of aerobic wetland cells is variable, ranging about 6.35 mm (0.25 inches) to 30.5 cm (12 inches) thick. Underlying Aerobic Wetland #3 is a 15.2 cm (0.5-foot) thick limestone layer. A small anoxic limestone drain (ALD) was constructed along the western edge of the reconstructed wetland to collect AMD seepage, with outlets into Cells #4 (oxidation pond #2) and #7 (aerobic wetland #3, Figures 6 and 7). This ALD is designed with a 12-hour retention time.

Table 4. Design Parameters: Untreated AMD Quality and Contaminant Load.

Parameter	Value	Units	Comments
pH	5.8	S.U.	typical value
Eh (estimated) 73	mv	typical	value
DO	0.48	mg/L	average values
Total Fe	450	mg/L	average value
D. Fe	400	mg/L	average value
D. Fe+3	20	mg/L	by subtraction
D. Fe+2	380	mg/L	average value
Al	0.4	mg/L	average value
Mn	15.0	mg/L	average value
Acidity	761.7	mg/L	average value
Alkalinity	180.0	mg/L	average value
Net Acidity	581.7	mg/L	by subtraction
Sulfate	3400	mg/L	average value
Flow 1	1.89	L/sec.	(30 GPM) from existing AMD line, average value
Flow 2	0.63	L/sec	(10 GPM) est. added from Western extension
Flow 3	0.32	L/sec	(5 GPM) est. to be collected seep adjacent to the wetland
Total Flow @ Inlet	2.52	L/sec	(40 GPM) @ 1st thru 5th cells
Total Flow w/ Seep	2.84	L/sec	(45 GPM) @ 6th and last cells

Contaminant Load Calculations

Acid loading = $2.52 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/d} \times 581.7 \text{ mg/L} \times 1 \text{ g/1000 mg} = 126,853 \text{ g/d}$

Fe loading = $2.52 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times 450 \text{ mg/L} \times 1 \text{ g/1000 mg} = 98,133 \text{ g/d}$

Mn loading = $2.52 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times 15 \text{ mg/L} \times 1 \text{ g/1000 mg} = 3,270 \text{ g/d}$

g/dSO_4 loading = $2.52 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times 3,400 \text{ mg/L} \times 1 \text{ g/1000 mg} = 741,254 \text{ g/d}$

PHASE II CONSTRUCTION

The Old Bevier II Project construction activity was between the summer and fall of 2001 with the new system treating the AMD since early October, 2001. Seven treatment cells are constructed, which includes, from the system inlet: oxidation pond #1, aerobic wetland #1, VFWS #1, oxidation pond #2, aerobic wetland #2, VFWS #2, and aerobic wetland #3 (Figures 6 and 7). To date, no cattails have been planted in the aerobic cells, but Missouri LRP plans on establishing cattails in the aerobic wetland cells in the spring of 2002.

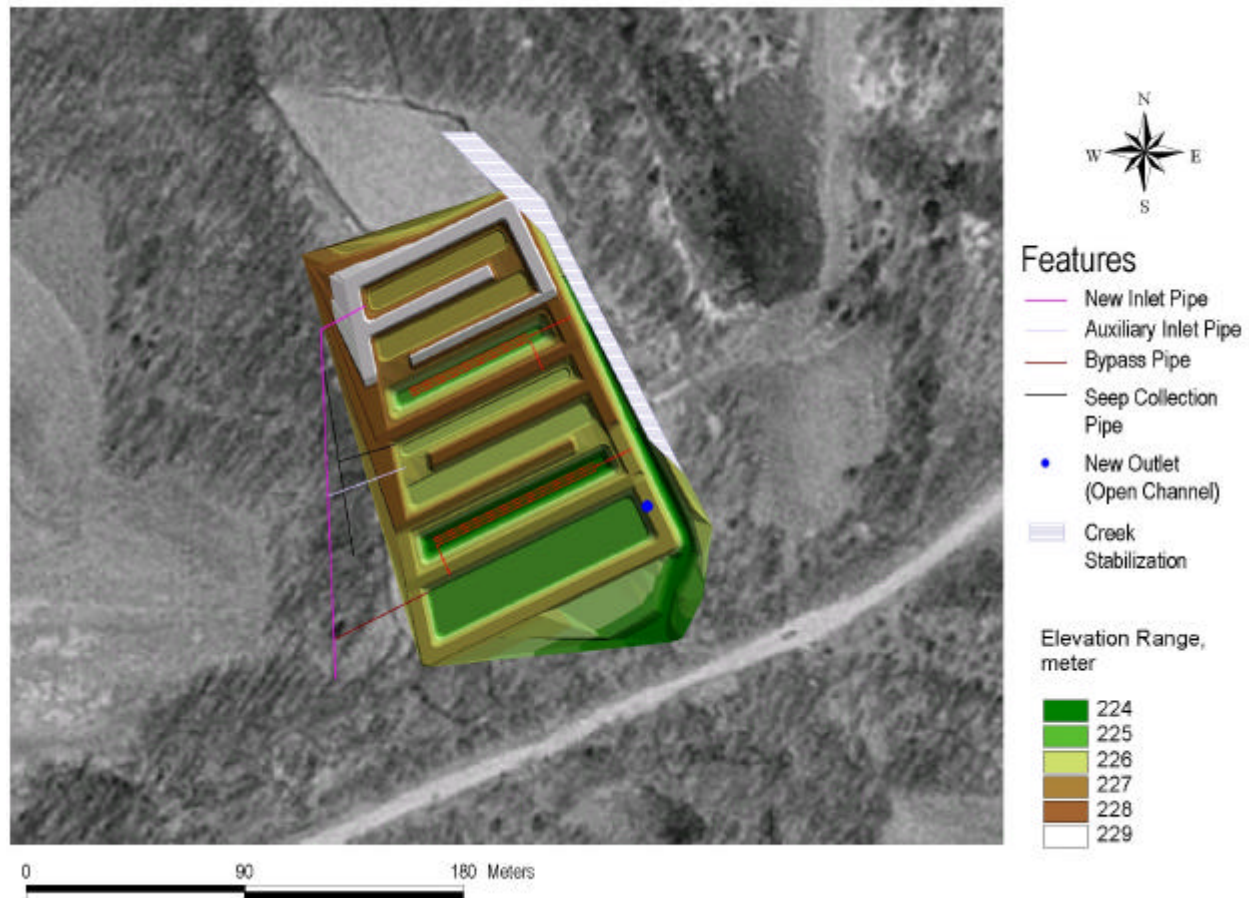


Figure 7. Topographic Model of the Old Bevier II Project (Note: Pipeline and N to S Creek Stabilization Locations).

SYSTEM EVALUATION

Preliminary post-remediation water samples were collected October 2001 through February 2002 and analyzed both by OSM-MCRCC and a commercial laboratory (Table 5). Water analyses indicate the system is operating as expected with a high iron removal rate initially, followed by reduced performance during the winter. Initially, the system was removing about 99% of the iron of a near neutral pH (6.95 S.U.) as measured at the system outlet. In October 2001, discharge was net alkaline at 152 mg/L. This amount of alkalinity is capable of neutralizing additional downstream AMD seeps. While the system was not specifically designed to remove manganese, measurements indicated that about 50% of the manganese was being removed. After three rounds of water tests, the mean iron removal is about 93% (Table 5) and

the mean discharge alkalinity is 119 mg/L. Given an estimated mean acidity of about 108 mg/L, a slight net alkalinity is expected in winter months with improvements anticipated during the summer when biotic activity, such as sulfate reduction, increases.

A collection system was added to the project to intercept small seeps from underground mines immediately west of the treatment cells. This water flows through a small ALD, and then because of elevation constraints of the seep outlets, flows directly into VFWS #2. The constructed collection system appears to capture only a small amount of AMD, and although discharge from the ALD is small, the increase in contaminant levels of the lower cells is measurable.

Performance of individual treatment system modules can be illustrated by plotting key chemical parameters against the linear distance along the system (Figures 8 – 12). The pH levels, which are reduced by metal oxidation and hydrolysis in the oxidation cells and aerobic wetland cells, receive a boost by the VFWS cells (Figure 8). The VFWS #1 mean pH increases about 1.3 standard units and VFWS #2 increases mean pH about 2.3 standard units. The estimated redox potential (Eh) acts in reverse with low values at the outlets of the VFWS underflow piping and higher values in the oxidizing environment of the aerobic wetlands (Table 5, Figure 10). The first oxidation pond and aerobic wetland remove iron. Then, after alkalinity is added with VFWS #1, additional iron precipitates (Table 5, Figure 11). Mean total iron levels at the discharge remain high at about 31 mg/L. Improvement in the iron removal rate is anticipated after emergent vegetation is established and biological activity seasonally increases. The oxidation cells are removing iron at a rate of between 13.9 and 17.5 g/day/m². Total alkalinity trends follow pH with reduction as the metal oxidation and precipitation reactions “use up” alkalinity (bicarbonate) and increase from each VFWS unit to about a level of 160 mg/L (Figure 12). Because of its gradual drop in concentration, along the system, manganese reduction does not appear to be co-precipitating with iron hydroxide. Most of the manganese reduction occurs in the latter cells as where iron is already at a lower concentration. Mean total manganese remains at about 7.9 mg/L at system outlet. Again, significant improvements in the system’s capacity to remove manganese are anticipated in summer after establishment of emergent vegetation. A limited amount of sulfate removal is occurring. Sulfate is lowered from a mean value of 2,355 mg/L in the inlet to 1,875 mg/L at the outlet of aerobic wetland #2. Seepage from the AMD seeps on the west end of VFWS #2 bumps up sulfate level to a mean value of 1,960 mg/L

Table 5. AMD Water Quality at the Old Bevier South Site following Rehabilitation¹

Parameter	Inlet	Oxidation Pond 1 Outlet	Aerobic Wetland 1 Outlet	VFWS #1 Outlet	Oxidation Pond 2 Outlet	Aerobic Wetland 3 Outlet	VFWS #1 Outlet	Aerobic Wetland: System Outlet	Units
Distance from Inlet	0.03 (0.1)	70.1 (230)	146.3 (480)	231.6 (760)	307.8 (1010)	393.2 (1290)	496.8 (1630)	588.2 (1930)	m. (ft.)
Mean pH	5.93	6.11	5.12	6.42	4.16	4.09	6.39	5.73	S.U.
pH Range	5.7 ~ 6.3	5.97 ~ 6.27	4.8 ~ 6.32	6.3 ~ 6.6	3.68 ~ 6.6	3.89 ~ 6.8	6.29 ~ 6.7	5.3 ~ 6.95	S.U.
Mean Eh	66	83	95	40	121	183	34	38	mV
Eh Range	45 ~ 80	78 ~ 88	46 ~ 143	29 ~ 49	59 ~ 183	172 ~ 194	30 ~ 39	20 ~ 60	mV
Mean DO	0.76	0.31	0.21	3.64	5.90	10.76	0.91	6.80	mg/L

DO Range	0.44 ~1.1	0.31	0.21	0.89 ~ 6.39	5.9	10.76	0.82 ~ 1	5.99 ~ 7.9	mg/L
Mean Alkalinity	178	105	59	154	73	30	162	119	mg/L
Alkalinity Range	164 ~195	88 ~ 115	16 ~ 84	131 ~ 178	0 ~ 150	0 ~ 90	149 ~ 184	71 ~ 152	mg/L
Lab Alkalinity	217							132	mg/L
Mean Acidity _{cal2}	823	618	555	442	306	111	180	108	mg/L
Acidity _{cal} Range	653~ 1163	543 ~ 762	447 ~ 730	272 ~ 604	222 ~ 353	57 ~ 165	140 ~ 219	62 ~ 154	mg/L
Net Acidity	645	513	496	288	233	81	18	-11	mg/L
Lab Acidity	683	470	680	440	390	79	35	20	mg/L
Mean Sulfate	2355	2263	2353	2223	2350	1875	2070	1960	mg/L
Sulfate Range	1800 ~3000	1800 ~ 3040	1900 ~ 3160	1900 ~2600	2000 ~ 2650	1550 ~ 2200	1650 ~2360	1520 ~ 2200	mg/L
Lab Sulfate	2900							2070	mg/L
Mean T. Fe	420.3	334.7	283.0	205.0	143.7	36.8	67.7	30.6	mg/L
T. Fe Range	352 ~ 514	298 ~ 364	234 ~ 352	148 ~ 251	115 ~ 175	12.4 ~ 85	28.5 ~ 111	4.5 ~ 56	mg/L
Lab T. Fe	474	434	439	328	246	22.8	115	71.9	mg/L
Cumulative Fe removal	0.0	20.4	32.7	51.2	65.8	91.2	83.9	92.7	%
Mean T. Mn	10.0	10.2	11.2	9.5	10.2	7.7	8.9	7.9	mg/L
T. Mn Range	7.8 ~ 12	7.5 ~ 12	7 ~ 13.5	7.4 ~ 12	6.4 ~ 16	7.5 ~ 7.8	6.5 ~ 10.75	6.8 ~ 8.74	mg/L

1. Samples were collected by OSM-MCRCC 9/26/01, 10/22/01, 1/23/02, and 2/21/02. On 9/26/01, the water b level in cell #6 was below the discharge level, and cell #7 was dry. Lab samples were collected on 1/23/02. Metals and sulfate values were determined using HACH DR890 colorimeter except lab value; field alkalinity was measured using HACH digital titration.
2. Calculated from pH and dissolved metal values using the formula:

$$3: \text{Metal Acidity (calc.)} = 50[2 \text{ Fe}^{2+}/56 + 3 \text{ Fe}^{3+}/56 + 3 \text{ Al}/27 + 2 \text{ Mn}/55 + 1000(10-\text{pH})].$$

CONCLUSIONS AND LESSONS LEARNED

Additional rounds of water sample collection with analysis by an EPA-certified laboratory are planned for in the spring and summer of 2002 to evaluate the success of the remediation effort and to investigate seasonal variations in both treatment and flow. The LRP may consider adding a bacteria-assisted manganese removal cell such as in inoculated limestone beds as suggested by Brant and Ziemkiewicz (1997) and in Robbins and others (1999). Future AMD treatment projects in Missouri which require VFWS technology should consider inclusion of: 1) either an aerobic wetland or limestone-lined drop structure before the oxidation pond to allow for more rapid aeration, 2) a schedule for construction that allows completion before winter to allow transplanting of locally-derived emergent plants, and 3) the transplanting of at least two species of emergent plants to limit impacts of infestation and disease. The experience gained in the original Old Bevier project showed that maintenance problems of a dilution supply pipeline,

particularly a pipeline positioned in an area that supports multiple land uses, may cause premature failure of an AMD passive treatment system. The Project Team plans additional evaluations through 2002.

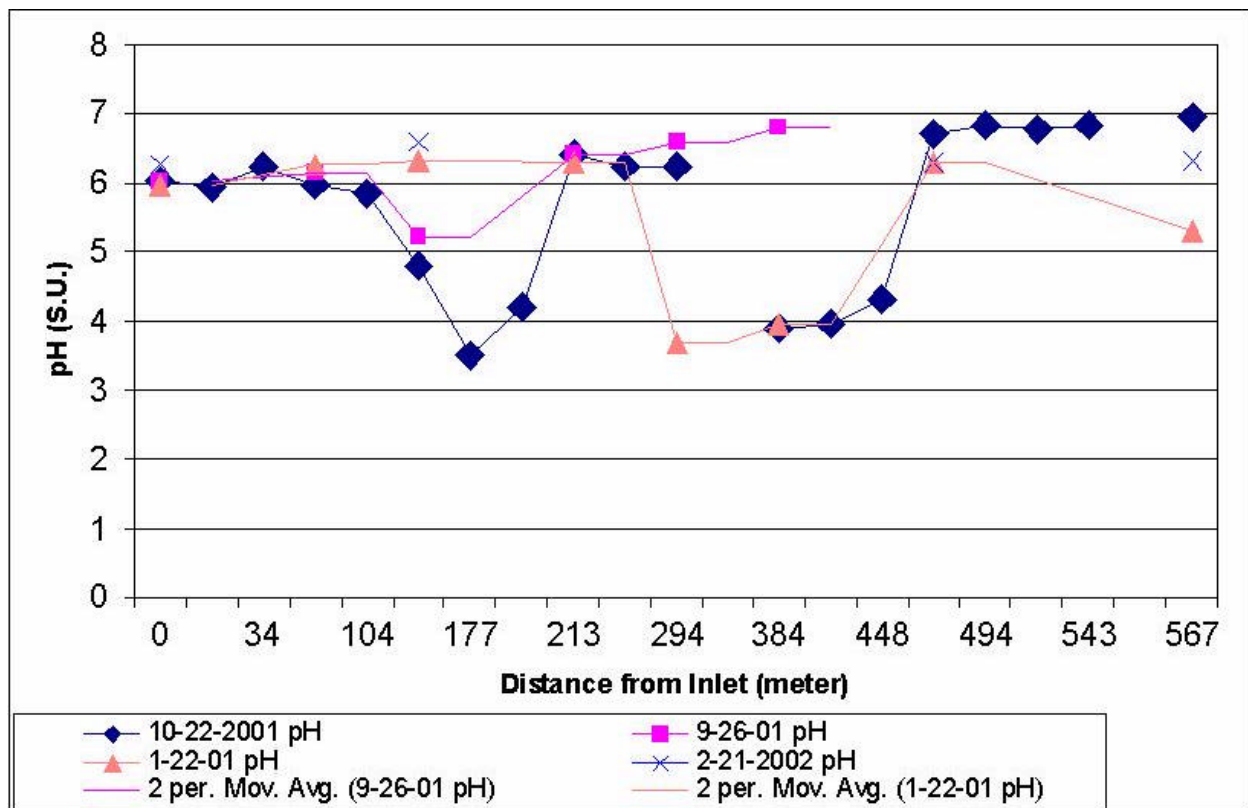


Figure 8. Changes in pH within the Old Bevier II Passive Treatment System.

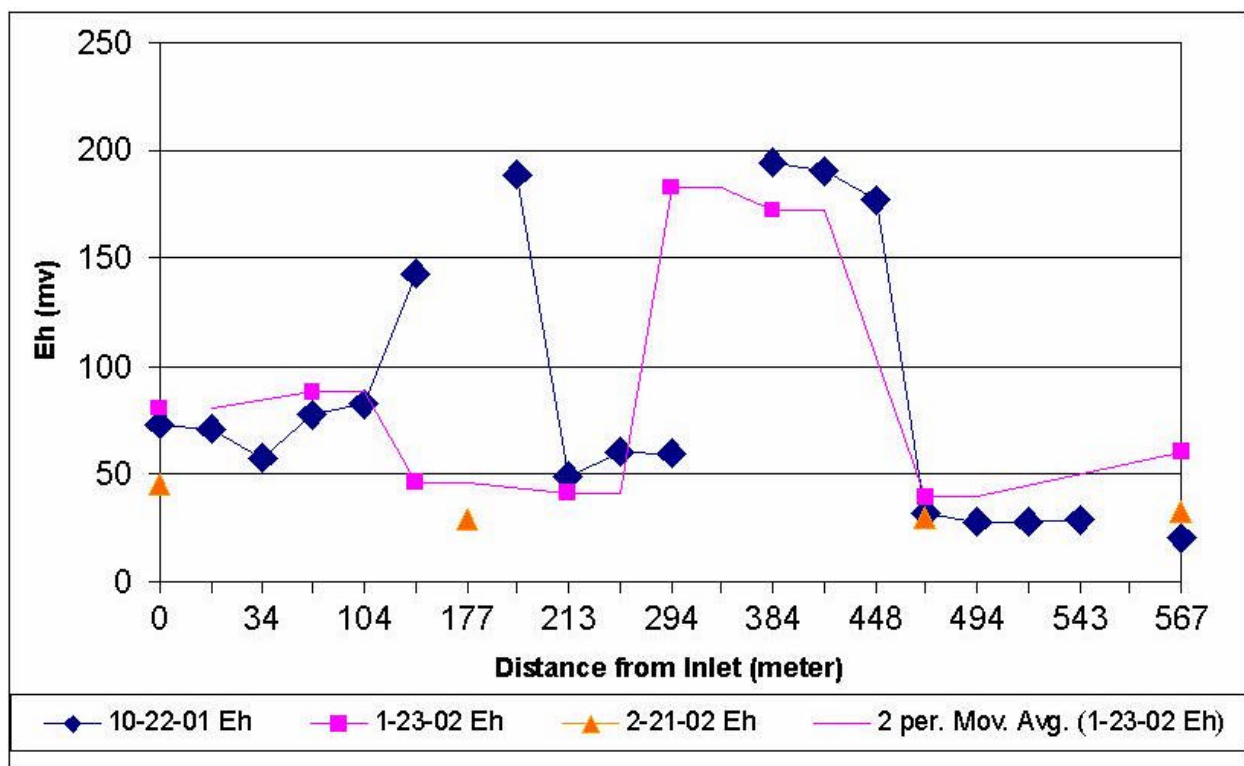


Figure 9. Changes in Eh within the Old Bevier II Passive Treatment System.

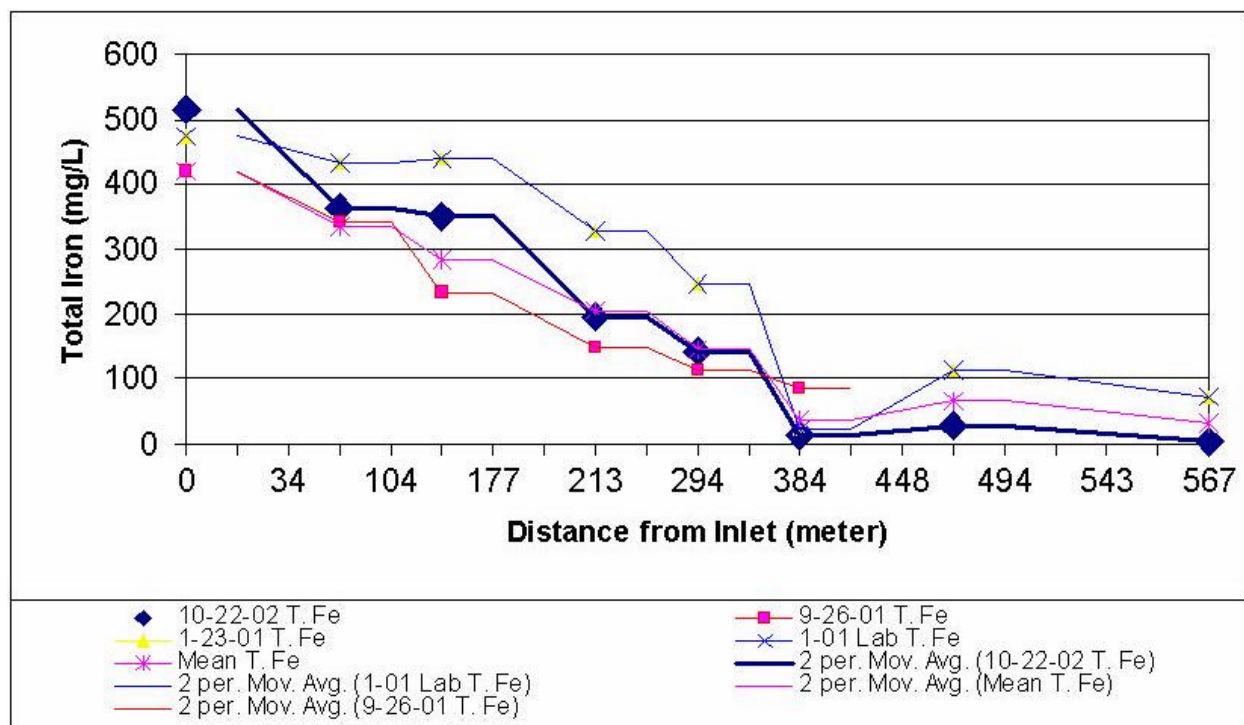


Figure 10. Changes in Total Iron within the Old Bevier II Passive Treatment System.

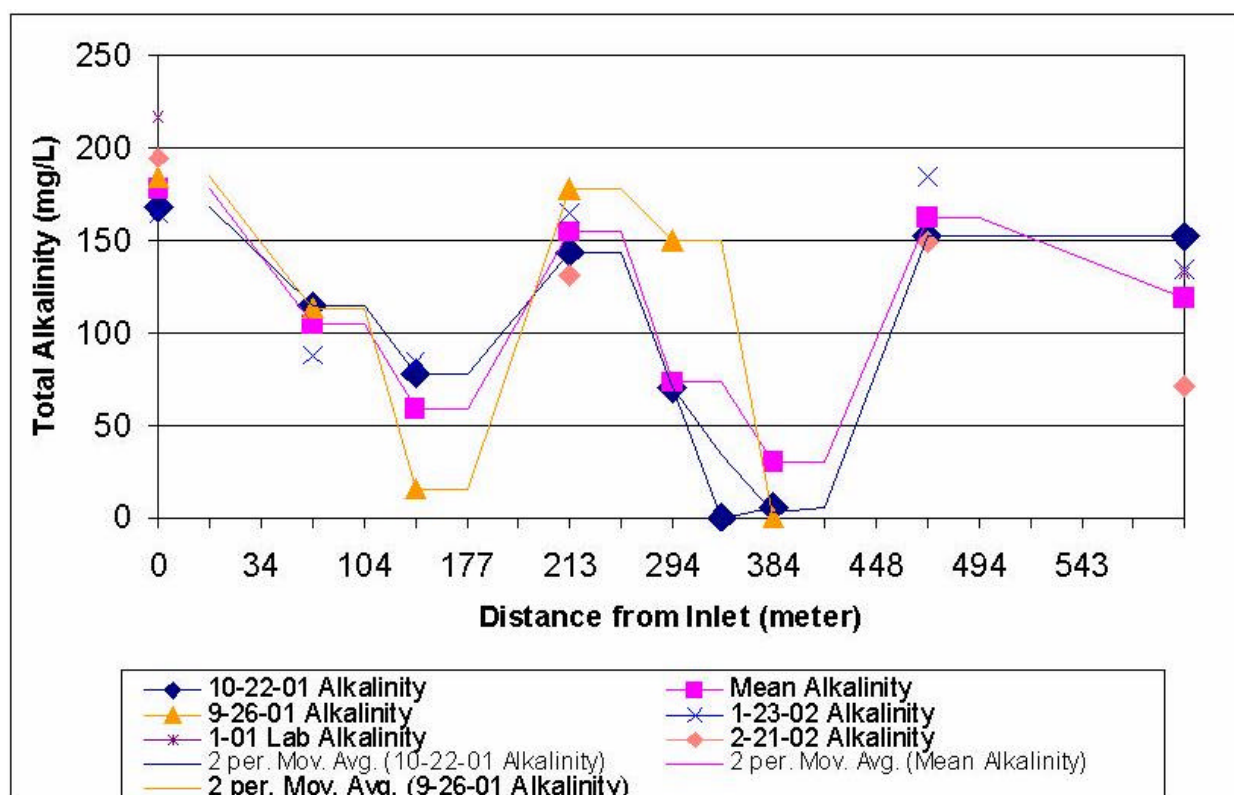


Figure 11. Changes in Total Alkalinity within the Old Bevier II Passive Treatment System.

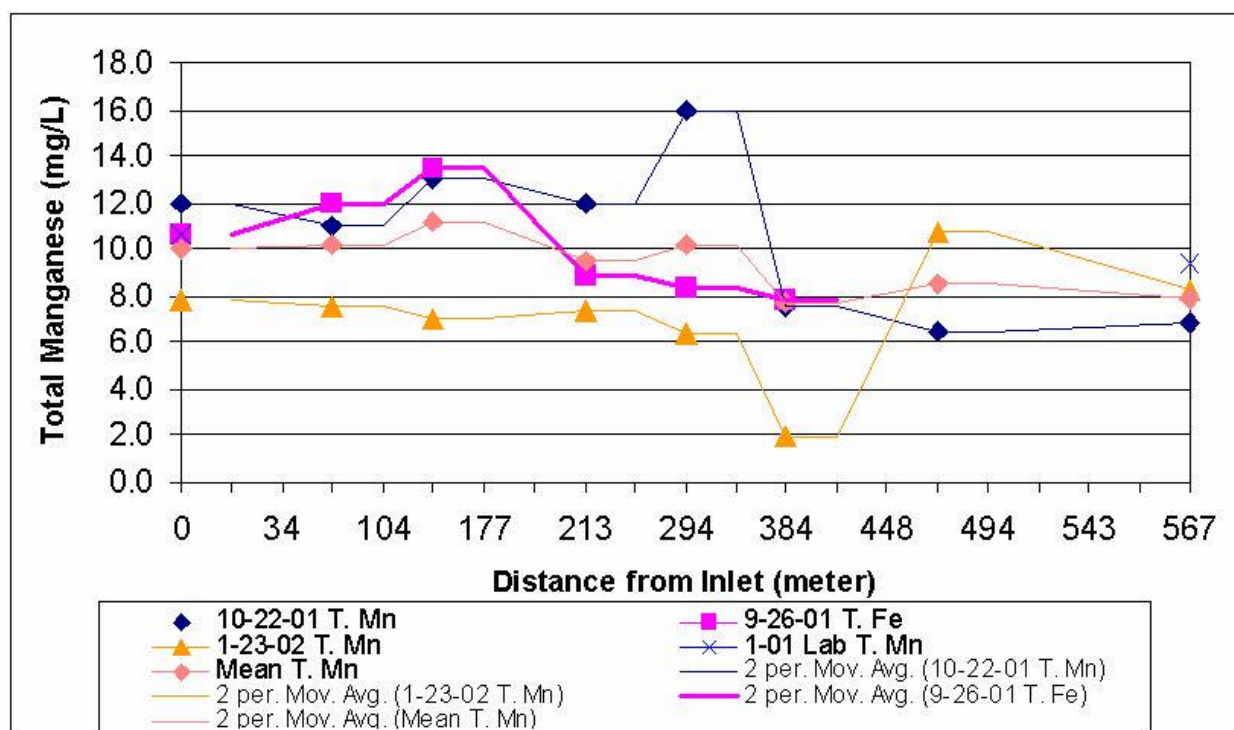


Figure 12. Changes in Total Manganese within the Old Bevier II Passive Treatment System.

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REFERENCES

- Behum, P. T., Jr., Kwang Kim, K. W. Garnett, Len Meier, and John Mehuys. 2001. Data Collection and Design Criteria For Construction of Passive Treatment of Acid Mine Drainage - Case Example: Rehabilitation of the Old Bevier Passive Treatment Wetland, Missouri. Poster presented at the U. S. DOI Conference on the Environment, March 13 – 15, Albuquerque, NM.
- Brant, D. L. and P. F. Ziemkiewicz. 1999. Passive Removal of Manganese from Acid Mine Drainage. *in* Proc. for the Fourteenth Annual Meeting of the A. Soc. For Surface Min. and Reclamation, May 10 –15, Austin, TX.
- Eaton, A. D., L. S. Clesceri, and A. E. Greensberg, Standard Methods for Examination of Water and Wastewater, 19th ed., American Public Health Assoc., Wash., D.C. publisher.
- Gentile, R.L. 1967. Mineral Commodities of Macon and Randolph Counties, Missouri Geol. Survey and Water Resources R. I. 40, 106 pp.
- Hare, Norman. 1992. The Old Bevier Reclamation Project. *Land and Water*, Jan. ed., 32 p.
- Hinds, Henry. 1912. The Coal Deposits of Missouri. Missouri Bureau of Geology and Mines. Vol. XI, Second Series. Hugh Stephens Printing Company.
- Hyman, D. M. and G. R. Watzlaf. 1995. Mine Characterization for the Successful Design and Evaluation of Passive Treatment Systems. *in* Proc. For the Nat. Assoc. of Abandoned Mine Land Programs. 17th Annual Conf., Oct. 15-18, 1995, French Lick, MO. p.170– 185.
- Robbins, E. I., D. L. Brant, and P. F. Ziemkiewicz. 1999. Microbial, Algal, and Fungal Strategies for Manganese Oxidation at the Shade Township Coal Mine, Somerset County, Penna. *in* Proc. for the Sixteenth Annual Meeting of the Am. Soc. for Surface Min. and Reclamation, August 13 –19, Scottsdale, AZ.
- Skousen, J., A. Rose, G. Geidel, J. Forman, R. Evans, W. Hellier, and Members of the Avoidance and Remediation Working Group of the Acid Drainage Technology Initiative (ADTI). 1998. Handbook of Technologies for Avoidance and Remediation of Acid Mine

- Drainage. Nat. Mine Land Reclamation Ctr., West Virginia Univ., Morgantown, WV publisher, 131 p. 235 – 242.
- Skovan, G. A. and C. R. Clouser. 1998. Design Considerations and Construction Techniques for Vertical Flow Wetland Systems. *in* Proc. for the Fifteenth Annual Meeting of the Am. Soc. for Surface Min. and Reclamation, August 17 –21, St. Louis, MO, p. 235 - 242.
- Watzlaf, G. R., and R. S. Hedin. 1993. A Method for Predicting the Alkalinity Generated by Anoxic Limestone Drains. *in* Proc. Fourteenth Annual West Virginia Surf. Mine Drainage Task Force Symposium, Morgantown, WV, April 27 – 28, 8 pp.
- Watzlaf, G. R. and D. M. Hyman, 1995, Limitations of Passive Systems for the Treatment on Mine Drainage. *in* Proc. for the Nat. Assoc. of Abandoned Mine Land Programs, 17th Annual Conf., Oct. 15-18, French Lick, MO, p.185–199.
- Wildeman, T. R., J. W. Dinkel, R. M. Smith, and M. L. McAllister. 1997. Field Assessment of Fe (III), Al, and Dissolved O₂ for Passive Treatment Options. *in* Proc. Fourth International Conf. on Acid Rock Drainage, Vancouver, B. C. May 31 – June 6, 1997, p. 1661 – 1672.